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**FINAL TECHNICAL REPORT**  
**"SCATTERING OF ACOUSTIC SIGNALS FROM THE UNDERSIDE OF SEA ICE"**  
**#N00014- -J-6004, UW #144-CB31**

**1. Purpose**

To study the properties of impulsive sound signals scattered by models of Arctic pack ice. The properties include the angular dependence and cross correlations of the scattered components.

**2. Background**

I was the leader of a team that made side scanning sonar measurements of the acoustic scattering and ridge structure of Arctic pack ice. Other members of the team were Dr. Jon Berkson and Dr. T.K. Kan. Our most careful set of data were taken near Fletcher's Ice Island (T3 then at 84°N, 84°W April 26-28, 1972). We made surface surveys to locate and measure the heights of ridges. These surveys were matched to our acoustic surveys. The acoustic surveys were made with a 48-kHz side scanning sonar. We used the sonar in a manual polar scanning mode. For display, the linear graphic records were cut into wedges and assembled in polar plots.

In one year old pack ice, the depths of ice keels were about 7 times the ridge elevations. The keels gave strong back scattered sound. The nature of the scattered signals indicates that the keels were rough. Practically no scattered sound came from the ice surface between ridges and keels. The distances between ridges were on the order of hundreds of meters. Reprints of our papers are attached.

Briefly, our conclusions were that the ice keels are rough and the surface between ridges is smooth. The roughness is not homogeneous. Acoustic scattering theories that use the spatial roughness spectra and assume the roughness to be homogeneous are unlikely to give good results.

**3. Research Task**

Research tasks are to make numerical studies of impulsive sound signals scattered and diffracted by models of the underside of Arctic pack ice. The models of the ice surface will be based on our data and data from R.E. Francois, Applied Physics Laboratory, University of Washington. Numerical code for computing the scattered and reflected signal at a rough sea floor was developed in the previous contract. The code will be modified for the Arctic studies. The numerical scattering studies will include the cross correlation of signals scattered to separated receivers. I will collaborate with Richard Keiffer in applying the NOARL three-dimensional facet ensemble model to sound scattering by Arctic pack ice. Also, laboratory acoustic experiments will be made to test crucial parts of the research.

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#### 4. Research Results

First is a review of data. Our under ice side scan sonar surveys were made with a 48-kHz Kelvin-Hughes side scan sonar. The transducer has a fan-shaped beam that is 1.5 by 51°. In conventional sonar surveys, the long axis of the transducer is horizontal and the fan-shaped beam is vertical. Under ice, ranges and directions of under ice features (PPI plots) were made by rotating the transducer with the fan vertical. The map of ice ridge A is shown in Figure 1. We made keel depth surveys using the fan horizontal. Details are in Berkson, Clay, and Kan (1973), Kan, Clay, and Berkson (1974), and Clay and Medwin (1977).

Sonar traces from the depth survey of ice ridges A, B, and C are shown in Figure 2. For these surveys, the vertical beam width of the fan is about 1.5°. The sonar traces are from transducer depths of 7, 11, and 18.5 m. Results of the measurements are sketched on Figure 3. The solid rectangles are the sonar data and the rest of the ice keel is my guess of a likely cross-section. The data show that the keel tilts toward the transducer and has an "under hang". The sonar trace for the 7 m depth shows much more reverberation than the trace for the 11 m depth. I originally thought that my seafloor facet reflection and diffraction code could be applied to this data. This was not the situation. The under hang of the keel gave much more reverberation than could be accounted for by single facet reflections and diffractions from wedge apices. Reflections from finite width facets and multiple reflections from combinations of facets were judged to be important.

The research was done in steps. A first step was to measure and do laboratory measurements and theory for the reflections from finite width plane facets. The geometry for these studies was chosen to minimize the interference of diffraction components from the boundaries of the facets. The results were published in a paper by Clay, Chu, and Li (1993). The problem of multiple reflections within a wedge is in the Biot-Tolstoy theory (Biot and Tolstoy, 1957; Tolstoy and Clay, 1987). While they prove that the image construction is exact for any wedge angle, details of how to do the image constructions required much careful analysis. Techniques and computations for finite width facets require even more work. Feuillade and Clay (1994) give the details of wedge image theory and algorithms in a paper on source locations in wedge wave guides. Since multiple diffractions can contribute to reverberations, we did research on multiple diffractions in reflection geometry. That research is in a paper submitted to the Acoustical Society of America (Li, Chu, and Clay, 1994).

Part of the task was to meet with scientists at Naval Research Laboratory-Stennis Space Center. Regular conferences were held with Chris Feuillade, Richard Keiffer, Wayne Kinney, Roger Meredith, Gerald Morris, and Jorge Novarini. Several of the scientists sent preliminary reports of their research for comments. These meetings formed the basis of fruitful interchanges of ideas and collaborations.

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Availability Codes	
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1	2
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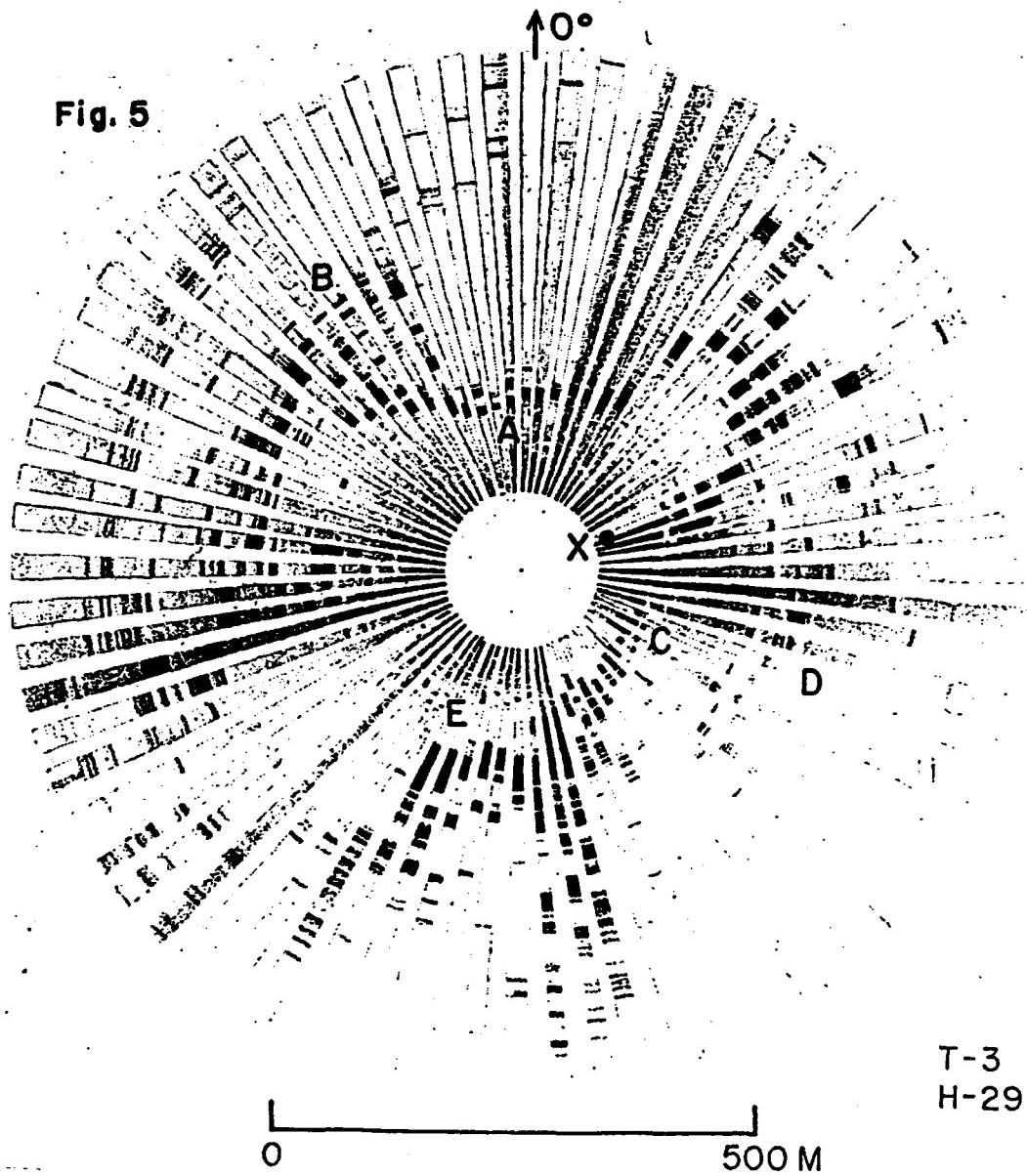
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**Fig. 5**



**Figure 1.** Sonar map from a location near Ice Island T3. (From Kan et al., 1974, Figure 5.)

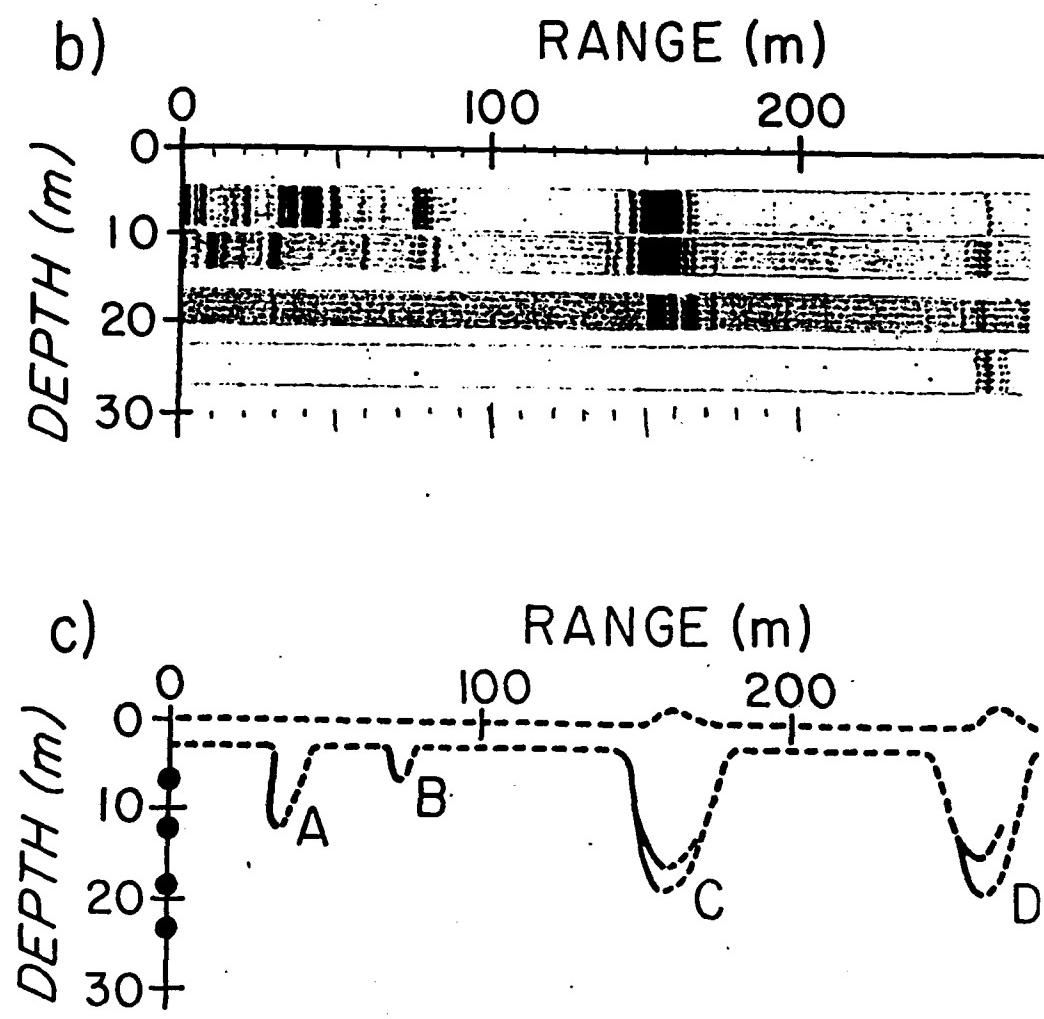


Figure 2. Depth survey of ice ridges near Ice Island T3. Ridge A is shown in the map in Figure 1.

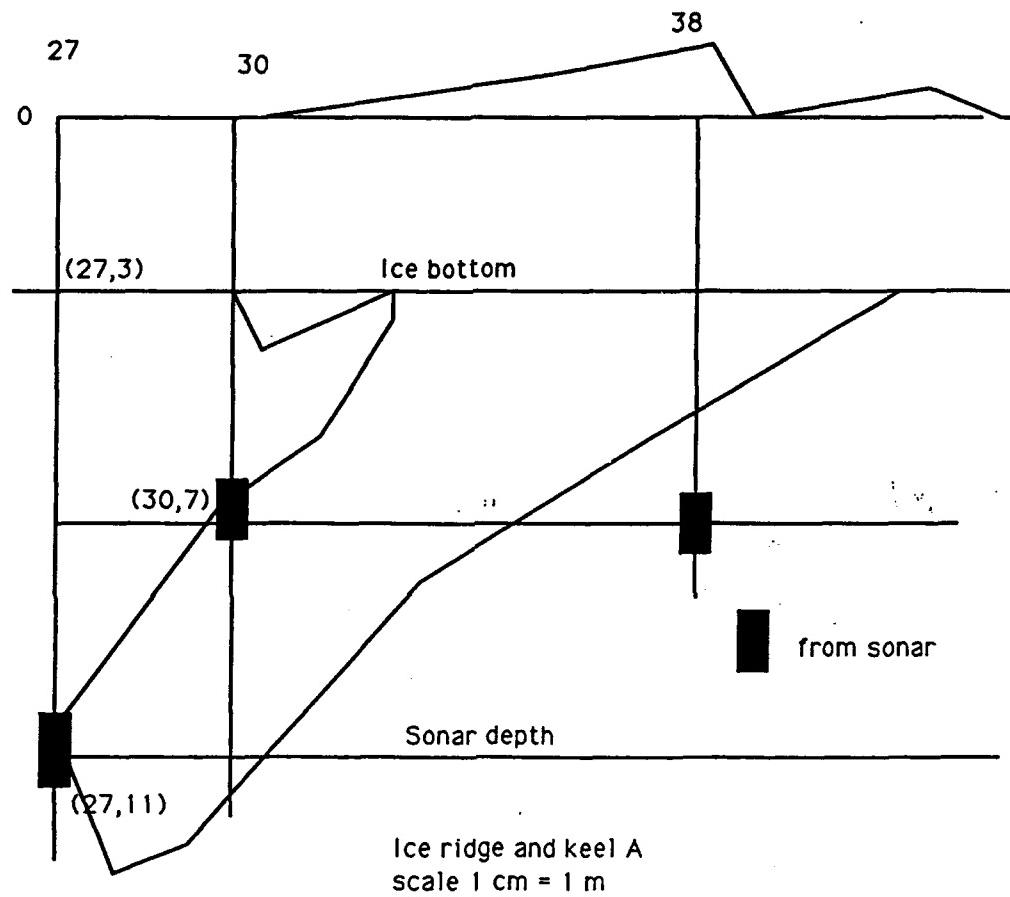


Figure 3. Cross-section of ice keel A. The sketch is based on data shown in Figure 2.